

Period-Luminosity-Colour Relation for Early-Type Contact Binaries

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ABSTRACT

This work describes the analysis of 64 early-type, massive contact or near-contact eclipsing systems from the Large Magellanic Cloud discovered by the OGLE-III survey. It presents the determination of the period-luminosity-colour relation followed by these objects, that is different from the one previously known for late-type W UMa stars. The relation for massive stars has a significantly steeper dependence on the colour, which is related to a much higher bolometric correction, however it is shallower in the period term. This leads to the conclusion, that the relation for the total population of main sequence contact binaries is non-linear. When studied separately, genuinely-contact and near-contact systems follow two slightly different relations.

Key words: stars: binary: eclipsing, stars: early-type, Magellanic Clouds

1 INTRODUCTION

Contact and close binary stars are known to form period-luminosity (PL) or period-luminosity-colour (PLC) relations due to the correlation between the radius of the orbit and the size of the components of the system. Systems with an ellipsoidal red giant component filling its Roche lobe form a PL relation in the range of periods from several to about 1000 days. It was discovered by Wood et al. (1999) and studied by Rucinski and Maceroni (2001), Soszyński et al. (2004, 2007) and most recently by Pawlak et al. (2014).

Another example is the relation formed by main sequence contact binary systems. The PLC relation for low-mass W UMa type stars have been studied in detail by Rucinski (1994, 2002, 2004), who used nearby stars with known parallaxes in order to calibrate the relation. While the scatter of the absolute magnitude derived from the PLC relation for W UMa stars is larger than for the pulsating stars, it can be very useful as a distance ruler because contact binaries are common and easy to detect with the time-series photometry. This method was used, for example, to verify cluster membership of W UMa type stars (Maciejewski et al. 2008, Kopacki et al. 2008, Li et al. 2010, Hu et al. 2011, Joshi et al. 2012).

While the PLC relation for late-type W UMa stars can be analysed based on the nearby objects, the situation is different for more massive stars. These are less abundant, therefore we do not have a statistically significant sample of such objects with known parallaxes. However, a large number of contact binaries were discovered during the third phase of the Optical Gravitational Lensing Experiment (OGLE-

III, Udalski 2003) project in the Large Magellanic Cloud (Graczyk et al. 2011), Small Magellanic Cloud (Pawlak et al. 2013) and Galactic disc (Pietrukowicz et al. 2013). The LMC sample is especially useful because of the well-known distance to this galaxy (Pietrzyński et al. 2013).

In this work, the analysis of early-type contact eclipsing binaries in the LMC is performed. The PLC relation they follow is found and compared with the results for the low-mass systems (Rucinski 2004). The structure of the paper is as follow: Section 2 gives the details on the analysed data, Section 3 presents the PLC relation obtained for the studied sample, Section 4 contains the discussion and Section 5 summarizes the results.

2 THE SAMPLE

The analysis is based on the sample of contact or very close systems from the OGLE-III catalogue of eclipsing binaries in the LMC (Graczyk et al. 2011). Out of the entire collection of light curves classified as contact, a subset of 64 systems having well-covered light curves, with low photometric noise, and a shape typical for a contact or near-contact binaries, was extracted. For such objects the transition from the minimum to the maximum of magnitude is smooth, and it is impossible to distinguish the eclipse from out-of-eclipse phase, even with precise photometry (Fig. 1).

Fig. 2 shows the positions of the selected objects in the colour-magnitude diagram. All of selected objects are bright and located in the LMC main sequence region or close to it.

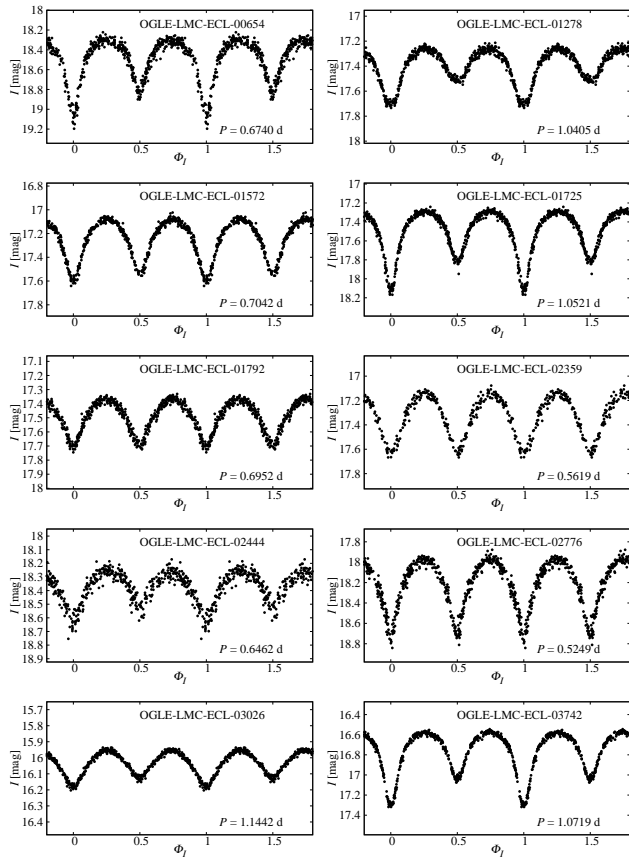


Figure 1. Example light curves of selected contact or close eclipsing binaries from the OGLE-III catalogue of eclipsing binaries in the LMC (Graczyk et al. 2011).

Therefore, these are most likely massive, early-type stars belonging to the LMC, and not foreground objects.

All of these objects lie in the area of the sky corresponding to the bar of the LMC, where the bulk of the OGLE-III coverage of the LMC was concentrated. Moreover, these are early-type stars belonging to the young population. Therefore, we expect them to be located in the centre of the LMC rather than in its halo. The geometric extent of the young population in the LMC can be limited by looking at the scatter of the PL relation for Classical Cepheids, which is equal to 0.07 mag (Soszyński et al. 2008). This value was obtained using Wesenheit index, therefore it is reddening-independent and corresponds only to geometric effects and internal scatter of the relation. The low geometric dispersion allows us to adopt for each of the systems the distance modulus (DM) of 18.49 ± 0.05 mag, obtained by Pietrzyński et al. (2013).

To calculate the absolute magnitude of each of the systems, the correction for the interstellar extinction is needed. The estimation of total extinction in the V -band (A_V) is done based on the LMC reddening maps (Haschke et al. 2011), using the transformation from $E(V-I)$ to A_V from Schlegel et al. 1998. To provide a better A_V estimation, the mean Red Clump (RC) colour was measured in the OGLE-IV fields located in the outskirts of the LMC (Udalski et al. 2015). The obtained value of $(V-I)^{RC} = 0.91$ mag minus the mean foreground reddening $E(V-I) = 0.04$ mag

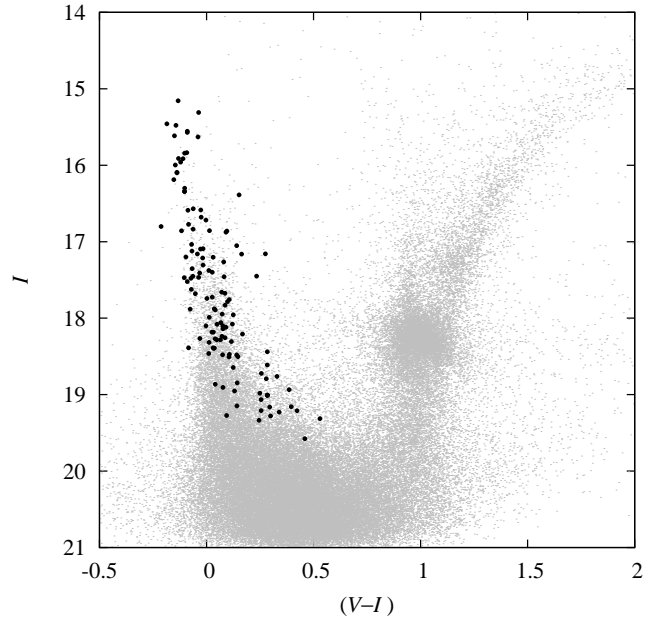


Figure 2. Colour-magnitude diagram for the OGLE-III LMC data, with marked contact binaries from the studied sample (black points). Selected objects clearly lie on the LMC main sequence or close to it. The field stars (grey dots) come from the OGLE-III photometric maps from one of the central LMC fields (Udalski et al. 2008).

from Schlegel et al. (1998) results in the mean reddening-free colour of the RC $(V-I)_0^{RC} = 0.87$ mag. This value is adopted instead of the $(V-I)_0^{RC} = 0.92$ mag colour used by Haschke et al. (2011), therefore the $E(V-I)$ obtained from the reddening maps is increased by the value of 0.05 mag, resulting from the difference in the RC colour used. The absolute V -band magnitude (M_V), in the maximum of the light curve for all of the studied systems, is calculated with the Eq. (1).

$$M_V = V - A_V - DM \quad (1)$$

The uncertainty in M_V is determined by the uncertainty of A_V , which in the studied sample is on average 0.19 mag. This is much higher than visual magnitude uncertainty or geometric scatter.

3 PERIOD-LUMINOSITY-COLOUR RELATION

The PLC relation for late-type (LT) W UMa type variables (Rucinski 2004) is quoted in the Eq. (2).

$$M_{V,LT} = -4.43 \log P + 3.63 (V-I)_0 - 0.31 \quad (2)$$

This form of the PLC relation was already proposed by Rucinski (1994), as a simplification of a theoretically derived formula, including also the bolometric correction (BC) and the mass ratio (q) dependent terms, which were neglected in the final calibration.

The BC is very small for low-mass main-sequence stars, therefore it is not surprising that the PLC relation works

well without explicitly including it. The situation is different for massive objects, for which the BC becomes significant. However, the BC is a function of temperature and therefore the colour as its indicator. Moreover, Nieva (2013) shows that the dependency between BC and temperature is linear for hot stars. Therefore, one can expect that the PLC relation will work properly in this case without explicit BC term, as this dependence is included in the colour term.

Another question is whether the q -dependent term in the relation is explicitly necessary. The precise determination of the q value is difficult based on photometric data only. While q can be estimated using a light curve synthesis code, such a solution requires the assumption of a given model (contact, semi-detached or detached), therefore it is strongly model dependent and can introduce additional errors to the final calibration. Reliable determination of q requires spectroscopic observations, but these are hard-to-obtain for faint binary systems. Moreover, W UMa stars tend to have similar, low q , therefore this factor is not expected to contribute significantly to the relation. Because of that Rucinski (1994) decided to neglect the q -dependent factor.

The situation changes a bit for massive systems, which have q spanning a wider range. However, there still remains the problem of reliable q determination. It cannot be done accurately based on photometric data only, and requires spectroscopic observations, which are unavailable for the studied sample. Therefore, this factor is also neglected in the calibration performed in this work. Further study, including spectroscopic analysis may allow for more precise calibration in this case.

Taking the above issues into account and assuming the same form of the relation (Eq. (2)) for early-type (ET) contact systems, the linear function of $\log P$ and dereddened colour $(V - I)_0$ is fitted, with the least square method, to the whole studied sample. The best fit obtained is given by Eq. (3).

$$\begin{aligned} M_{V,ET} = & -2.97(\pm 0.51) \log P \\ & + 8.27(\pm 0.73) (V - I)_0 \\ & - 0.59(\pm 0.15) \end{aligned} \quad (3)$$

The distribution of the sample in the PLC space, together with the relation fitted, is presented in Fig. 3. The systems clearly group in the plane given by the relation, however, its scatter is relatively large. The RMS for the obtained fit is 0.52 mag, which is two times larger than in Rucinski (2004).

For further study, the sample is visually divided into two groups: genuinely-contact systems, where the two components are in thermal equilibrium (light curves with two equal minima), and near-contact systems, which are close, but still detached or semi-detached and therefore not in a thermal contact (light curves with minima of different depth). As it can be seen in Fig. 4, near-contact systems tend to lie below the PLC relation fitted for the entire sample. This is consistent with a similar result obtained by Rucinski and Duerbeck (1997) for low-mass W UMa type stars.

Projections of the obtained PLC relation onto the $\log P - M_V$ and $(V - I)_0 - M_V$ planes are shown in Fig. 5. It can be seen that the PL relation itself has a large scatter and does not allow for precise estimation of M_V without

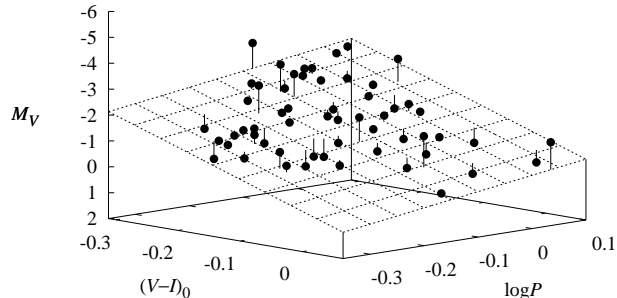


Figure 3. PLC relation obtained for the sample of 64 contact or near-contact, early-type binary systems from the LMC.

adding the colour term, due to the strong correlation between colour and absolute magnitude resulting from higher BC. It also explains a relatively high uncertainty of the $\log P$ term in the PLC relation.

The tight correlation of M_V with $(V - I)_0$ and rather poor with $\log P$ arise a question if two independent variables are really needed to calibrate the relation. To test it a linear function of $(V - I)_0$ only is fitted to the data. The RMS of such fit is 0.65 mag, which worse than the one obtained for a two parameter fit ($RMS = 0.52$ mag). The decrease of scatter suggests that using the PLC relation is justified. However, it should be tested, if this decrease is significant from the statistical point of view, as it can be related to the reduced number of degrees of freedom, caused by adding another parameter of the fit.

To verify this, the F -test is performed for the residuals of the two fits. The value of the test statistic for the two variances is $F = 1.52$ making it almost equal to the critical value for 62 and 61 degrees of freedom which is $F_{62,61} = 1.53$, for the significance level $p = 0.05$. While the result of the test is a borderline case, it rather suggests to reject the hypothesis that the two variances are equal, what leads to the conclusion that the full PLC relation gives a better fit.

For further verification, the analysis of the residuals of the one-variable fit is done. If the period dependency was absent, the residuals of colour-magnitude relation should be flat, without a noticeable correlation with the period. However, such correlation is clearly visible in Fig. 6, where residual of the colour-magnitude fit are plotted as a function of $\log P$. This strongly indicates, that the period dependency is significant in the proper calibration of the relation, even though it may at first look blurred by much stronger colour dependency.

Finally, the presence of the period term is also consistent with the physical interpretation of the problem. All above leads to the conclusion, that two variables are indeed necessary. Analogous question has also been discussed by Rucinski (2006) for W UMa stars where a similar conclusion was reached.

In the next step, the PLC relation is fitted separately for each of the two previously defined groups (Fig. 7). The

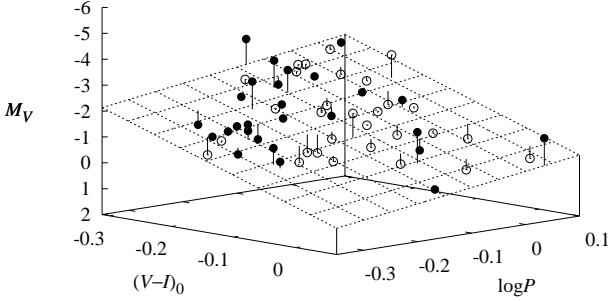


Figure 4. PLC relation for the sample divided into genuinely-contact (filled circles) and near-contact (open circles) systems. Near-contact binaries lie mostly below the relation obtained for the entire sample.

result is given by Eq. (4) for genuinely-contact (GC) systems and by Eq. (5) for near-contact (NC) systems.

$$\begin{aligned}
 M_{V,GC} = & -3.47(\pm 0.87) \log P \\
 & + 7.57(\pm 1.21) (V - I)_0 \\
 & - 0.97(\pm 0.26)
 \end{aligned}
 \quad (4)$$

$$\begin{aligned}
 M_{V,NC} = & -3.41(\pm 0.60) \log P \\
 & + 8.56(\pm 0.80) (V - I)_0 \\
 & - 0.40(\pm 0.15)
 \end{aligned}
 \quad (5)$$

While the period term is very similar in both relations, the colour term differs in larger degree, which can be related to the colour shift present in genuinely-contact systems which are in thermal equilibrium. However, the colour terms in the two equations are consistent with each other, as well as with the one in the first relation for the entire population, within 2σ range. As for the period term this consistency is even within 1σ range. It is also worth noticing that the relation for near-contact systems shows tighter correlation with the $RMS = 0.40$ mag, whereas the one for genuinely-contact binaries is 0.55 mag.

For a typical period and colour configuration for the studied sample ($\log P = -0.1$, $(V - I)_0 = -0.2$) the M_V estimations given by the two relations differs by 0.37 mag. This value, which is within 1σ range of both relations, tells how big error is made if a wrong model is assumed.

4 DISCUSSION

The relation obtained for early-type contact binaries from the LMC (Eq. (3)) differs significantly from the one known for late-type systems (Eq. (2)), even taking into account the relatively high uncertainty of the coefficients of $\log P$ and $(V - I)_0$ terms in the Eq. (3). Fig. 8 presents the absolute magnitudes the original relation for late-type systems would yield if naively used for the sample of early-type systems analysed here. This clearly shows that the relation for

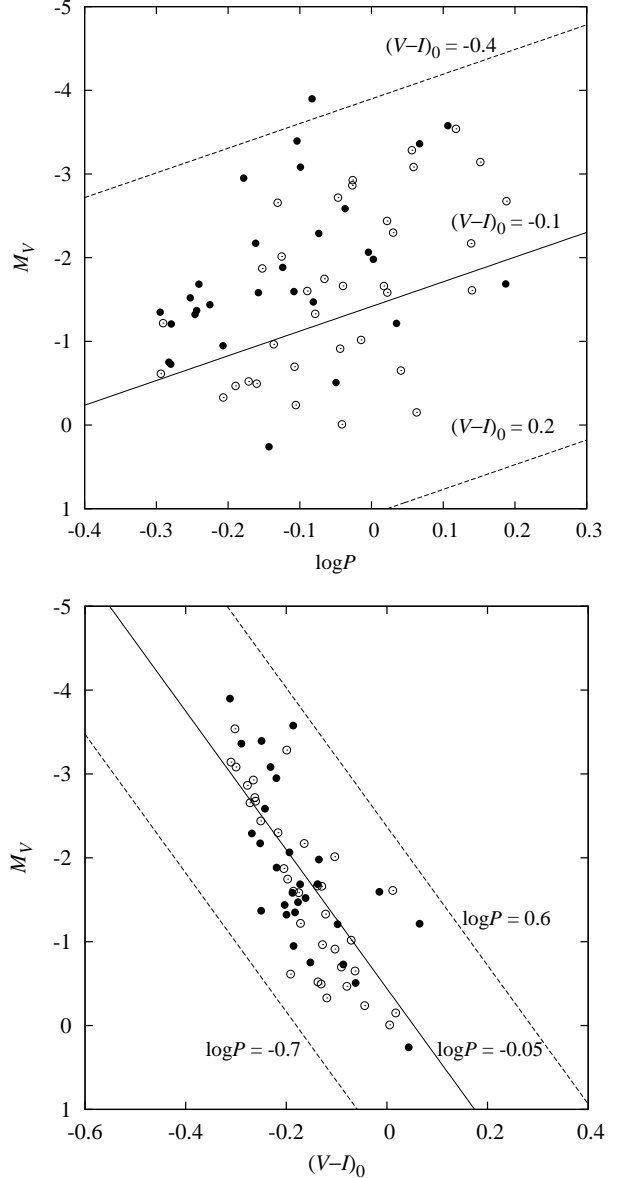


Figure 5. Projections of the PLC relation (see Fig. 3) into $\log P - M_V$ (upper panel) and $(V - I)_0 - M_V$ plane (lower panel). Projections of the PLC plane along three different lines are marked on each of the panels. Near-contact systems (open circles) tend to lie below genuinely-contact systems (filled circles) in the upper panel (similara as in Fig. 4), while no significant separation is visible in the lower panel.

the entire population is non-linear. The attempt to simply extend the results obtained for low-mass objects results in the M_V estimation on average fainter by 1.2 mag. The main reason of this is the bolometric correction, which is small or even negligible for late-type stars, becomes significant for, blue, hot stars. This results in the much steeper colour dependence for the early-type systems. However, it should be noted that the period dependence for massive stars also differs significantly from the one for low-mass systems.

While the formula obtained for the high-mass systems (Eq. (3)) fits the data (Fig. 9), the scatter of the points

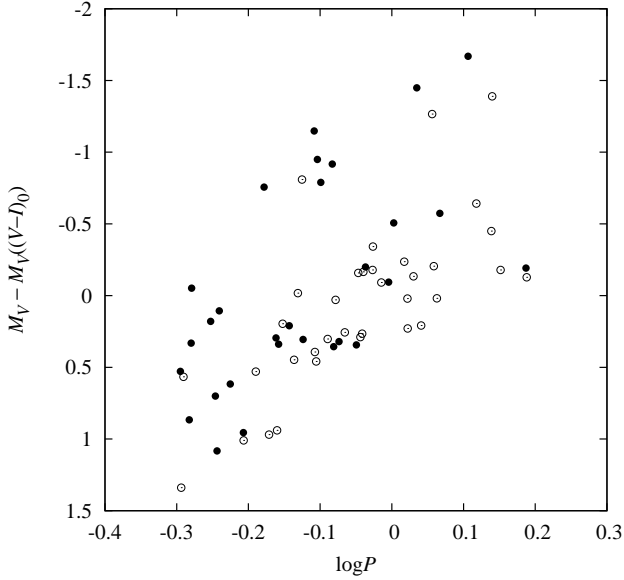


Figure 6. Residuals of the one variable fit as a function of $\log P$. A clear correlation is visible, showing that the relation using $(V-I)_0$ dependency only is not sufficient and that the period term is needed. One may suspect a division into the two types depending on the type of the light curve, as expected for systematically differing sizes of genuinely-contact (filled circles) and near-contact (open circles) binaries.

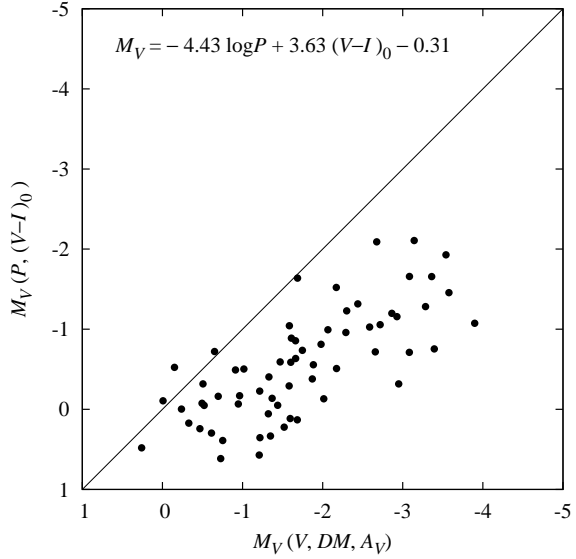


Figure 8. An attempt to naively extend the relation obtained by Rucinski (2004) for the late-type stars and use it for early-type objects. The absolute magnitudes calculated using the distance to LMC are given on the horizontal axis, while the ones obtained from the PLC relation - on the vertical axis. It can be seen that relation obtained for late-type stars gives on average fainter absolute magnitudes than expected.

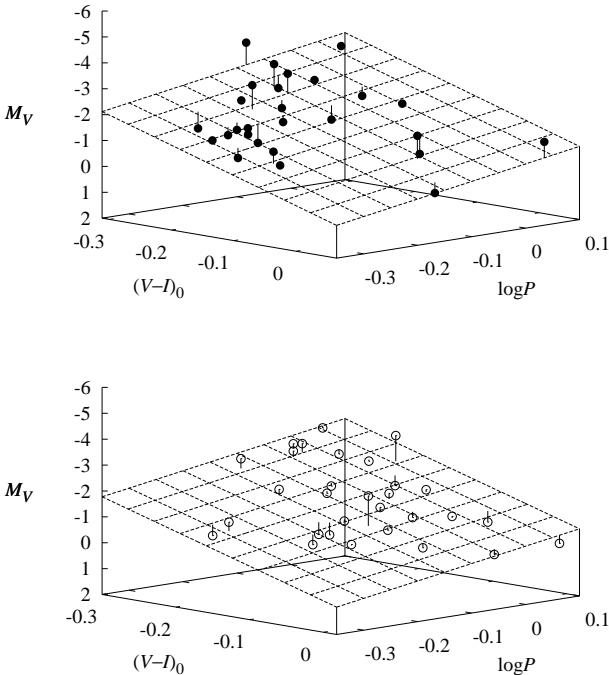


Figure 7. PLC relation fitted separately for genuinely-contact (upper panel) and near-contact (lower panel) systems.

around it is large. The $RMS = 0.52$ mag is large compared to the accuracy given by Rucinski (2004) for low-mass systems. This is related to a few factors. First, the obtained value of M_V for systems in the LMC may not be as accurate as the values for nearby stars, especially due to the fact that reddening correction needs to be applied. This introduces uncertainty of about 0.19 mag on average.

The assumption that all of the studied systems are at the same distance ($DM = 18.49$ mag) also contributes to the scatter of the relation. However, this contribution, while non-negligible, is much smaller than the uncertainty of the reddening maps. For objects studied by Pietrzyński et al. (2013), where precise determination of distance to individual objects was performed, the differences between the mean DM to the LMC and to a given object are smaller than 0.04 mag. Even assuming the upper estimate of the geometry-related uncertainty of 0.07 mag based on the scatter of the Classical Cepheids PL relation (Soszyński et al. 2008), it is still much smaller than 0.19 mag, related to the reddening correction.

The large scatter of 0.52 mag relative to the predicted linear relation (Eq. 3) requires an explanation. Most likely, the main contributing factors are our lack of knowledge of the mass-ratio q and our inability to distinguish between binaries in genuinely good contact from those which are lumped here under the name of near-contact ones. The latter may be versions of semi-detached binaries. For contact binaries, the efficient thermal transport equalizes the effective temperature over the common radiating surface. In contrast, the energy transport is apparently entirely or partially absent in near-contact binaries. The strong dependence on the configuration couples with the value of q . For genuine contact binaries, both the absolute magnitude and colour should

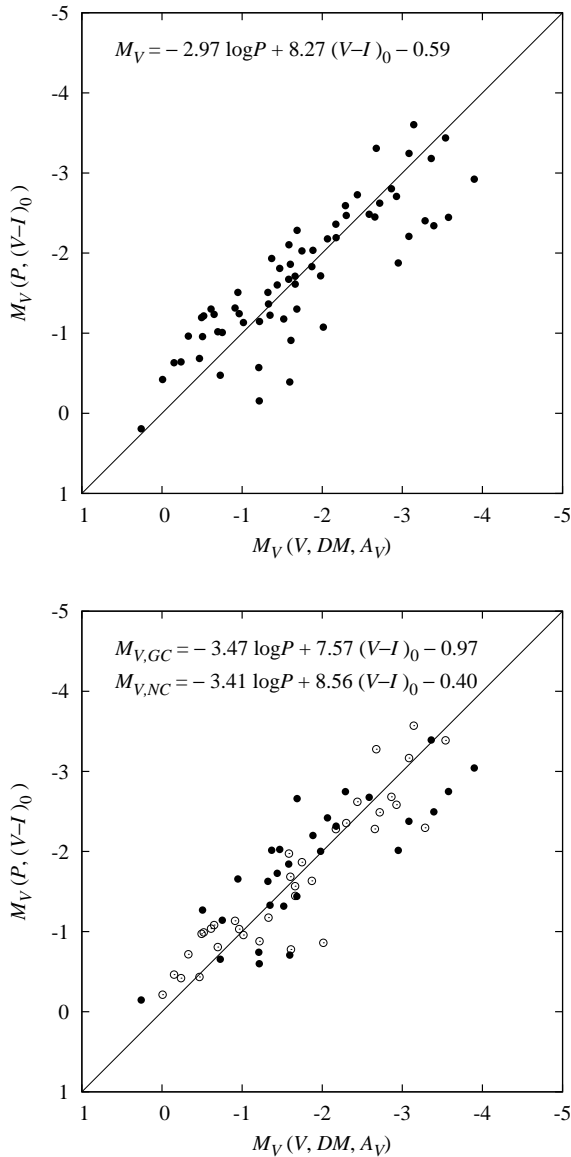


Figure 9. PLC relation fitted for the entire sample (upper panel) and genuinely-contact and near-contact systems separately (lower-panel). Description of the axes the same as in Fig. 8. The fit is slightly better when two separate relations are used.

be affected in a predictable way, while the combination of the magnitudes and colours is much harder to predict and not so obviously dependent on q for near-contact binaries.

It should be noted that none of the objects used in this determination has a spectroscopically determined q while photometrically determined values of q are model dependent since light curve synthesis fits require assumption on the system configuration. For contact binaries, the dynamically permitted range extends from $q = 0.09$ (Rasio 1995, Arbutina 2007, 2009) to unity ($q = 1$). For two identical stars, regardless of the model, the system should be simply two times brighter. Thus, the magnitude is then increased by 0.75, while the colour is unaffected. But, for any $q < 1$, the situation is different depending if the system is a genuinely-contact or a near-contact one. In a contact binary, for a de-

creasing value of q , the secondary component provides progressively less luminosity while it contributes a large amount of the common radiating area. In fact, the area stays relatively large down to small values of q . Thus, for smaller values of q , the result is a substantial modification of the colour of the contact binary with usually only a moderate modification of the absolute magnitude (Mochnacki (1981), Rucinski and Duerbeck (1997)). This picture applies only to binaries in perfect thermal contact. In contrast, we have currently no consistent model for near-contact binaries which appear to be common among early-type binaries.

Another factor ignored so far and that may potentially play a role here is metallicity. Rucinski (2002) suggests that a small metallicity-dependent correction is necessary to obtain accurate absolute magnitude value. However, Rucinski (2004) claims that explicit metallicity factor in the relation can be neglected, and PLC relation itself gives good results for objects of different metallicity.

The objects in the studied sample belong to the same population and environment (the LMC bar and disc), therefore all of them should have similar metallicity. Because of that the PLC relation obtained for them is expected to be self-consistent without including explicit metallicity factor. However, the difference in average metallicity of the LMC and Galactic stars may contribute to the difference of the relations obtained by Rucinski (2004) and in this work.

5 SUMMARY AND CONCLUSIONS

The analysis of early-type contact binaries from the LMC shows that they follow a PLC relation which is different from the one obtained for low-mass W UMa stars (Rucinski 2004). The relation obtained for the analysed systems is significantly steeper in the colour term than the one for late-type binaries and less steep in the period term. This leads to the conclusion that the relation for the entire population of contact binaries is non-linear. While studied separately genuinely-contact and near-contact systems follow slightly different relations with the near-contact relation having smaller scatter.

While massive contact or close binaries clearly follow the PLC relation, its scatter is quite high. It is related to the physical properties of the system and a large diversity of possible configuration of system components and their mass ratios. The main reason of the large RMS is likely the lack of precise information on the q value of a given system, which is impossible to obtain from the photometric data only. Different q values lead to different magnitude and, in the case of genuinely-contact systems, colour shifts dependent on the type of secondary component. For close, but non-contact systems where the second mentioned effect is absent, the scatter of the relation is smaller. Further study, including spectroscopic observations, may allow for more precise determination of the PLC relation.

There are also systematic uncertainties contributing to the scatter of the relation, especially related to the dereddening of the stars based on the extinction maps. While the metallicity factor can be neglected for the studied sample, as it is expected to be similar for all studied objects, it may be necessary to take it into consideration while studying the whole population of W UMa stars.

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 Udalski, A., Szymański, M. K., and Szymański, G. 2015, Acta Astron. 65, 1
 Wood, P. R. et al. 1999, in IAU Symposium, 191

Table 1. Basic parameters for the objects studied in this work. IDs are adopted from Graczyk et al. (2011).

ID	RA	DEC	M_V	$(V - I)_0$	$\log P$	type
OGLE-LMC-ECL-00654	04:45:24.73	-67:47:33.8	-0.521	-0.137	-0.171301	near-contact
OGLE-LMC-ECL-01278	04:49:53.60	-68:58:50.3	-1.661	-0.129	0.017263	near-contact
OGLE-LMC-ECL-01572	04:51:06.09	-69:35:40.8	-1.871	-0.205	-0.152281	near-contact
OGLE-LMC-ECL-01725	04:51:39.44	-70:42:22.5	-1.584	-0.175	0.022083	near-contact
OGLE-LMC-ECL-01792	04:51:55.98	-69:29:04.8	-1.582	-0.186	-0.157848	genuinely-contact
OGLE-LMC-ECL-02444	04:54:01.87	-67:01:36.1	-0.468	-0.079	-0.189630	near-contact
OGLE-LMC-ECL-02776	04:54:52.22	-67:08:03.4	-0.728	-0.087	-0.279861	genuinely-contact
OGLE-LMC-ECL-03026	04:55:32.53	-69:28:27.1	-3.083	-0.300	0.058536	near-contact
OGLE-LMC-ECL-03742	04:57:16.75	-70:12:51.2	-2.300	-0.216	0.030166	near-contact
OGLE-LMC-ECL-03778	04:57:20.43	-67:02:24.3	-2.950	-0.220	-0.178228	genuinely-contact
OGLE-LMC-ECL-03780	04:57:20.58	-68:52:37.8	-3.284	-0.199	0.056293	near-contact
OGLE-LMC-ECL-03838	04:57:30.57	-68:49:50.4	-3.394	-0.249	-0.103829	genuinely-contact
OGLE-LMC-ECL-04189	04:58:21.49	-67:16:38.2	-2.290	-0.268	-0.073589	genuinely-contact
OGLE-LMC-ECL-04341	04:58:48.47	-66:57:53.8	-1.322	-0.200	-0.246135	genuinely-contact
OGLE-LMC-ECL-05322	05:01:36.42	-67:37:18.8	-1.470	-0.177	-0.081093	genuinely-contact
OGLE-LMC-ECL-05389	05:01:47.05	-70:54:08.7	-2.586	-0.242	-0.036790	genuinely-contact
OGLE-LMC-ECL-05906	05:03:00.41	-70:20:38.8	-2.927	-0.265	-0.026323	near-contact
OGLE-LMC-ECL-05977	05:03:10.27	-67:52:00.5	-0.151	0.018	0.062884	near-contact
OGLE-LMC-ECL-06062	05:03:20.89	-68:58:26.4	-0.008	0.005	-0.041275	near-contact
OGLE-LMC-ECL-06121	05:03:30.51	-69:54:54.7	-0.752	-0.152	-0.282502	genuinely-contact
OGLE-LMC-ECL-06667	05:04:43.35	-70:19:48.3	-1.349	-0.183	-0.294782	near-contact
OGLE-LMC-ECL-06731	05:04:50.84	-70:08:58.9	-3.361	-0.289	0.067021	genuinely-contact
OGLE-LMC-ECL-06745	05:04:52.91	-70:33:01.8	-0.948	-0.186	-0.207001	genuinely-contact
OGLE-LMC-ECL-07009	05:05:29.38	-70:31:53.4	-2.718	-0.263	-0.046756	near-contact
OGLE-LMC-ECL-07050	05:05:35.36	-67:03:11.6	0.260	0.043	-0.142969	genuinely-contact
OGLE-LMC-ECL-07378	05:06:14.93	-69:09:02.9	-0.507	-0.062	-0.049429	genuinely-contact
OGLE-LMC-ECL-08338	05:08:32.69	-71:13:38.5	-3.577	-0.186	0.106351	genuinely-contact
OGLE-LMC-ECL-08909	05:09:51.75	-69:02:03.9	-2.171	-0.164	0.138865	near-contact
OGLE-LMC-ECL-09001	05:10:04.09	-69:37:02.2	-0.238	-0.044	-0.105518	near-contact
OGLE-LMC-ECL-09055	05:10:11.76	-69:06:25.6	-1.208	-0.098	-0.279223	genuinely-contact
OGLE-LMC-ECL-09283	05:10:46.07	-67:36:11.5	-2.864	-0.277	-0.026775	near-contact
OGLE-LMC-ECL-09482	05:11:14.51	-69:16:18.1	-1.980	-0.135	0.002582	genuinely-contact
OGLE-LMC-ECL-09689	05:11:52.92	-69:11:25.6	-1.884	-0.219	-0.123840	genuinely-contact
OGLE-LMC-ECL-09787	05:12:06.83	-68:56:45.0	-0.329	-0.119	-0.206667	near-contact
OGLE-LMC-ECL-10351	05:13:32.97	-68:49:57.4	-0.697	-0.090	-0.107291	near-contact
OGLE-LMC-ECL-10542	05:13:59.88	-69:04:55.7	-2.675	-0.261	0.188063	near-contact
OGLE-LMC-ECL-11003	05:15:07.52	-66:38:24.7	-1.747	-0.197	-0.065596	near-contact
OGLE-LMC-ECL-11541	05:16:28.73	-67:53:28.9	-3.539	-0.302	0.117821	near-contact
OGLE-LMC-ECL-11769	05:17:03.35	-69:42:04.8	-2.065	-0.194	-0.004378	genuinely-contact
OGLE-LMC-ECL-12030	05:17:43.90	-67:55:20.4	-2.173	-0.252	-0.161479	genuinely-contact
OGLE-LMC-ECL-12415	05:18:35.41	-67:51:23.9	-3.142	-0.310	0.151689	near-contact
OGLE-LMC-ECL-12649	05:19:10.04	-68:00:37.3	-1.369	-0.250	-0.243720	genuinely-contact
OGLE-LMC-ECL-12802	05:19:33.33	-69:04:37.1	-1.610	0.012	0.140016	near-contact
OGLE-LMC-ECL-12866	05:19:44.67	-67:53:30.5	-1.595	-0.015	-0.108202	genuinely-contact
OGLE-LMC-ECL-12878	05:19:45.70	-71:14:19.2	-3.082	-0.231	-0.099056	genuinely-contact
OGLE-LMC-ECL-12982	05:19:59.86	-68:15:09.2	-3.898	-0.312	-0.083027	genuinely-contact
OGLE-LMC-ECL-13206	05:20:36.00	-69:26:09.1	-1.602	-0.186	-0.089552	near-contact
OGLE-LMC-ECL-14291	05:23:05.58	-69:35:03.1	-1.329	-0.122	-0.078460	near-contact
OGLE-LMC-ECL-14617	05:23:49.28	-69:14:21.9	-2.439	-0.251	0.021698	near-contact
OGLE-LMC-ECL-15444	05:25:54.31	-69:27:24.1	-1.684	-0.172	-0.240697	genuinely-contact
OGLE-LMC-ECL-15756	05:26:35.01	-69:52:14.6	-0.495	-0.131	-0.160075	near-contact
OGLE-LMC-ECL-16083	05:27:11.41	-69:50:53.3	-1.686	-0.138	0.187106	genuinely-contact
OGLE-LMC-ECL-18264	05:31:36.39	-68:59:24.7	-1.520	-0.162	-0.252703	genuinely-contact
OGLE-LMC-ECL-18865	05:32:56.86	-70:44:37.2	-1.438	-0.203	-0.225302	genuinely-contact
OGLE-LMC-ECL-19039	05:33:19.72	-69:37:19.7	-1.663	-0.138	-0.039738	near-contact
OGLE-LMC-ECL-20231	05:36:02.21	-69:24:32.3	-2.657	-0.272	-0.130987	near-contact
OGLE-LMC-ECL-21029	05:37:46.54	-67:47:36.9	-0.912	-0.103	-0.043745	near-contact
OGLE-LMC-ECL-21066	05:37:50.51	-71:39:53.7	-1.218	-0.172	-0.290562	near-contact
OGLE-LMC-ECL-21744	05:39:32.41	-71:32:21.8	-1.017	-0.071	-0.014624	near-contact
OGLE-LMC-ECL-21983	05:40:05.29	-68:28:35.2	-1.214	0.065	0.034789	genuinely-contact
OGLE-LMC-ECL-22275	05:40:47.88	-70:01:27.9	-2.014	-0.104	-0.125227	near-contact
OGLE-LMC-ECL-23809	05:45:24.37	-69:38:21.7	-0.613	-0.191	-0.293656	near-contact
OGLE-LMC-ECL-24776	05:50:00.45	-70:09:06.2	-0.964	-0.128	-0.136344	near-contact
OGLE-LMC-ECL-25114	05:52:18.19	-71:53:42.9	-0.651	-0.063	0.040922	near-contact